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THE IMPLEMENTATION OF INNOVATION PROGRAM REPORT: 3 IN 1 ANION BED OPERATING PATTERN FOR WATER EFFICIENCY AND WATER POLLUTION LOADS IMPROVEMENT

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Abstract:
In Tuban Regency, East Java, Indonesia, PT PLN Nusantara Power Unit Tanjung Awar-Awar Power Plant was built. There are two 350 MW coal-fired plants in operation. The company is committed to the environment. They hire a highly skilled team to run water treatment plants (WTP). To solve problems caused by the WTP, the company carefully analyzed data and observed actual conditions. The goal is to address efficiency, safety, and environmental impact. A challenge of WTP operation is the limited ability of ion exchange resin (Anion) to remove impure ions from raw water. Thus, PLN introduced a new program, "THE IMPLEMENTATION OF 3 IN 1 ANION OPERATION PATTERN". The primary purpose of the program is to reduce the frequency of anion bed component replacement. As the WTP has two anion beds, this operating method is possible. The first three days of operation are spent using Anion Bed-A, while Anion Bed-B remains on standby. We contributed to 1) the anion bed replacement, cut from once a month to once every three months, and 2) significant reductions in wastewater pollution load in 2022 of TSS=0,000624 tonnes and CL=0.00000714 tonnes. Those savings are equivalent to IDR 1,164,543,907,450.67. Since the new system is more efficient and easier to maintain, production is more efficient and less expensive. When we implemented a 3 in 1 anion pattern to WTP, we reduced the environmental impact using the scientific method of Life Cycle Analysis (LCA).

Keywords: Anion Operation Pattern, Water Treatment Plants, Coal-Fired Power Plants, Life Cycle Analysis

INTRODUCTION

Perseroan Terbatas (PT) Perusahaan Listrik Negara (PLN) Nusantara Power Unit Tanjung Awar-Awar Power Plant was built in Tuban Regency, East Java, Indonesia. The company operates two coal-fired power plants with 350 MW capacity each (Wegie & Darmawan, 2023). This project is built based on Presidential Regulation of the Republic of Indonesia Number 71 of 2006, dated July 5, 2006 (Hartono et al., 2020), concerning the Assignment to PT PLN to provide electricity to the community. The regulation states that the government has assigned PT PLN to organize the procurement and construction of a coal power plant at the specified location and with the operating schedule as determined. In implementing the rapid construction of power plants, all permits relating to Environmental Impact Analysis (AMDAL), acquisition and compensation for transmission lines, and land acquisition processes are completed within a maximum period of 120 days by the responsible government departments.

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The company is solidly committed to the environment. Its goal is to reduce its carbon footprint. In addition, it utilizes a state-of-the-art combustion process that is more efficient and cleaner than traditional coal-fired power plants. The highly skilled technicians and engineers also contribute significantly to smooth operation. A high standard is maintained by monitoring the performance of power generation technology, conducting regular inspections, and addressing maintenance and repair issues to meet quality standards.

To support the improvement of the environment around the power plant, PT PLN Nusantara Power Unit Tanjung Awar-Awar implements several programs, including monitoring and evaluating flora and fauna, monitoring the diversity of flora and fauna in the water, developing mini aquaponics, cultivating radiant plants, creating green energy for co-firing, planting mangroves in the Mentoso village, growing catfish in the Kaliuntu village, and cultivating Gibas goats in the Kaliuntu village. These programs significantly impact the local community by promoting environmental conservation, supporting sustainable livelihoods, and enhancing the overall well-being of the residents in the surrounding areas (Home, 2024).

By analyzing the data and observing the actual operation conditions in the field, PT PLN Nusantara Power Unit Tanjung Awar-Awar solves the water treatment plant (WTP) problem. The solution improves efficiency, safety, and cost savings. There are limitations of ion exchange resin (Anion) to remove impure ions from raw water (Kobielski et al., 2022). If the anion bed reaches saturation, it indicates that it needs to be replaced. In water filtration systems, regular anion bed replacement is very critical; it maintains the performance of the negative ion binding device, which produces pure demineralized water (Werth et al., 2020). However, too frequent replacement of anion beds impacts environmental pollution, chemical use, and the excessive use of demineralized water during the flushing stage of the replacement operation (Yang et al., 2023). It is a severe problem for our company, the environment, and the living things around it.

PT PLN Nusantara Power Unit Tanjung Awar-Awar is dedicated to minimizing water pollution from waste and optimizing water usage efficiency. In 2022-2023, PLN introduced an enhanced program called "THE IMPLEMENTATION OF 3 IN 1 ANION OPERATION PATTERN". This program was developed to address the frequent need to replace anion beds. The regeneration of components and chemicals directly impacts the usage of demineralized water and waste generation (Li et al., 2019). Under this new process, the anion bed filter is operated for three days, followed by one standby day. This approach helps reduce the filter bed's workload and flow rate, thus optimizing the negative anion exchange process.

Consequently, the frequency of anion bed component replacement is reduced. This operating method is feasible because the WTP has two units of anion beds: Bed-A and Bed-B. During the first three days of operation, Anion Bed-A is utilized, while Anion Bed-B remains on standby. As a result of this revised operating pattern, the saturation level in the anion bed has decreased. This decrease in saturation level enhances equipment durability and reduces the need for chemical usage. Moreover, component replacement is less frequent and adversely affects the water supply.

We contribute to the following aspects by implementing the 3 1 anion operation pattern:

1. Component replacement: The anion bed replacement has been reduced from once a month before the program to once every three months after the program has been completed.
2. Environmental: In 2022, there were significant reductions in wastewater pollution load, with TSS=0,000624 tonnes and $CL_2 = 0.00000714$ tonnes. That is equivalent to IDR 1,164,543,907,450.67 in cost savings.

In the following sections, we include related works introducing three essential reviews for the research findings and contexts: coal-fired power plants, water purification and demineralization,

and an exchange column for anion bed. The methodology section contains the improvement process flowchart, basic calculation, and the cost savings calculation. In implementation and result, we talk about the pre-implementation conditions, post-implementation conditions, the environmental impact of the innovation programs, the calculation of the innovation program, savings calculations, innovation programs add value, and innovation programs toward the scope of life cycle assessment (LCA) study. The last of our paper is the conclusion section.

Related Work

Coal-Fired Power Plants. A coal-fired power plant is a thermal power station that converts the chemical energy of coal into electrical energy by burning it (Yang et al., 2019). This type of power plant is among the oldest and most widely used to generate electricity. Several countries utilize coal as a fuel source for electricity generation due to its widespread availability and low cost (Oberschelp et al., 2019).

Coal-fired power plants work by using steam to generate electricity. The coal is pulverized into a fine powder and burned in a furnace. The furnace produces heat, which boils water to produce steam. The steam is then expanded through turbines, which generate mechanical power. This mechanical power is then converted into electrical energy by a generator. The steam is then condensed back into water, and the cycle is repeated (Shen et al., 2018).

Burning coal releases greenhouse gases, such as carbon dioxide, which are non-renewable energy sources. As a result, climate change, deforestation, and air pollution occur. The release of sulfur dioxide, nitrogen oxides, and particulate matter from coal-fired power plants can also negatively affect human health and the environment (Zhang et al., 2023). Coal-fired power plant companies have implemented several actions to reduce their negative environmental impact. These include: 1) Carbon Capture and Storage (CCS): CCS technology captures and buries carbon dioxide emitted from coal-fired power plants (Bui et al., 2018). 2) Emission Control Technologies (AECTs): AECTs remove pollutants from flue gas, improving air quality (Nie et al., 2019). 3) Integration of renewable energy sources: Coal power plants can be integrated with renewable energy sources, such as solar and wind power. 4) Efficiency: Improve the efficiency of coal-fired power plants to reduce greenhouse gas emissions (Li et al., 2020).

Water Purification and Demineralization. Water purification and demineralization are essential to ensure water quality and purity for various purposes (Bodzek, 2019). Water is treated by removing various contaminants and minerals to improve its taste and quality.

Water purification can be accomplished using various methods (Bolisetty et al., 2019). These methods can be categorized into two main groups: physical and chemical methods. These methods are:

1. Physical Methods: a) Filtration involves passing water through a filter to remove solid particles like dirt, sand, and suspended solids. b) Distillation: This method involves boiling the water, collecting the evaporated steam, and condensing it into a liquid. Condensed water is free of contaminants and minerals. c) Filtration with Activated Carbon: Carbon filters are commonly used for water purification. The process removes organic compounds, pesticides, and volatile organic compounds (VOCs). d) Ultraviolet (UV) Disinfection: UV lamps kill bacteria, viruses, and other microorganisms in water.
2. Chemical Methods: a) Chlorination: Chlorine is added to water to kill bacteria and microorganisms. It is an effective disinfectant but leaves a residual taste and odor. b) Chlorine Dioxide: Chlorine dioxide is also effective against microorganisms but less harsh on the environment. c) Ion Exchange: This method involves exchanging water ions with those from a

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resin bed. It treats water with a low mineral content. d) Ozonation: Ozone is added to water to destroy microorganisms. It is an eco-friendly method that produces no chemical residuals

Demineralization refers to removing dissolved minerals from water (Boulahfa et al., 2019). The technology is widely used in various fields, including water treatment, pharmaceuticals, and the manufacture of high-purity water. Steps involved in demineralization include:

1. Preliminary Treatment: This step removes suspended solids, organic matter, and sediments from the water.
2. Deionization: The water is then passed through ion exchange resin beds. The resin attracts and exchanges the ions in the water, leaving behind pure demineralized water.
3. Post-Treatment: In some applications, additional treatments like reverse osmosis or distillation may be performed to purify the water further.

Purification and demineralization are essential for the following reasons: Quality and Safety, Health Benefits, Industrial Applications, and Environmental Conservation. The purification and demineralization of water are fundamental processes to ensure its quality and safety for various purposes (Bharati et al., 2024). By removing contaminants and minerals, these procedures improve water quality, enhance taste, and promote a healthy lifestyle.

Ion Exchange Column for Anion Bed. Ion exchange systems remove negatively charged ions (anions) from fluids, typically water, with anion bed filtration (Levchuk et al., 2018). These systems are used in water purification, wastewater treatment, and chemical processing. Anion bed filtration systems for demineralization result in highly purified water by removing cations and anions (Zhang et al., 2022). Anion exchange resins and cation exchange resins are often used to achieve demineralization.

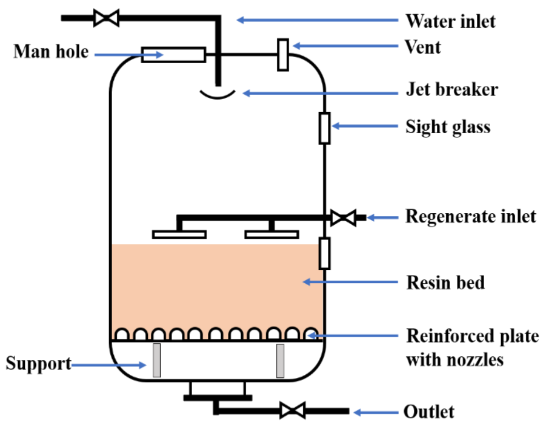

Figure 1. Co-Flow Regenerated Column

Figure 1 shows the co-flow regenerated column. The explanation of the figure: the top of the column has an entry point for water. A simple jet breaker prevents the incoming water stream from disturbing the resin bed surface. The column usually has an ample freeboard approximately the same height as the resin bed. The purpose of this is so that the resin can be backwashed inside the column to remove suspended solids accumulated on the bed surface. A maintenance hole is required to inspect and possibly repair the column inside (shown on the left).

Furthermore, two sight glasses are shown, one at the top and one at the level of the resin bed. Also, the top of the column must have an air vent to allow the water to drain out for inspection or resin replacement. The vessel's bottom collector is a crucial feature: a densely distributed plate of

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nozzles is one of the most common types. Stainless steel plate to which nozzles are attached. The regenerant is sometimes distributed uniformly throughout the vessel by a regenerant distributor positioned in the center.

METHODS

Improvement process flowchart, the water treatment plant installation flowchart.

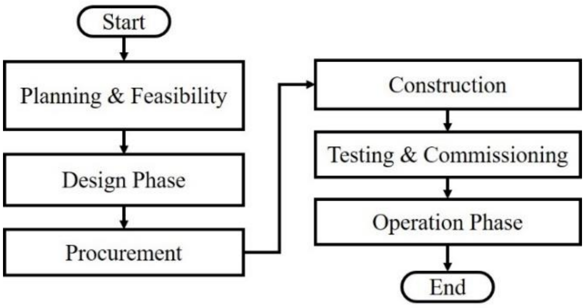

Figure 2. The Flowchart of the Improvement Process

The improvement process starts with planning and feasibility, as shown in Figure 2. The first activity is planning, in which we identify the need, analyze current water supply and demand, and evaluate the issues related to water quality. The feasibility study entails conducting a site selection analysis, estimating costs and funding options, and evaluating the project's environmental impact. After the feasibility study, we also perform regulatory compliance, which includes obtaining all necessary permits and approvals and ensuring compliance with local, state, and federal regulations. In the design phase, there are three activities: preliminary design, detailed design, review and approval. Preliminary design: We develop basic design concepts and identify significant components (intake, treatment, storage, distribution). Then, for the detailed design, we create technical engineering drawings, specify the materials and equipment, and develop construction plans and schedules (Taufik et al., 2024). The review and approval process involves communicating with managers and commissioners about designs for regulatory review and revising designs based on feedback. Procurement is a process of acquiring goods and services from external sources. Equipment is purchased. It is necessary to order treatment equipment and materials. Organize the delivery and storage of the materials. The construction process was carefully planned and managed to ensure a successful result. This step includes building the foundation, the construction of structural components, the installation of equipment, and the installation of treatment units. Testing and commissioning are the processes of testing all components of a system to ensure that it functions correctly and optimally. It involves system testing, initial equipment testing, pressure and leak testing, monitoring water quality and flow rates, and training personnel on operation and maintenance. The operational phase is the final stage of a project, where project outputs are implemented and handed over. During this phase, handovers will be conducted, control will be transferred to operational staff, routine maintenance and repairs will be performed, and regulatory reports will be prepared.

The Basic Calculation. Absolute value calculation:

$$|At_{abs}| = \bar{Q}_{water} \times t_{operation} \quad (1)$$

$|At_{abs}|$ is the absolute value calculation, $\bar{Q}_{water}$ is the water flow average, and $t_{operation}$ is the operation time. Absolute value calculation is the total volume of water flowing per unit of time.

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$$F_{RPB}(Wt) = G \times V_{wpl} \tag{2}$$
$$F_{total} = F_{RPB}(TSS) + F_{RPB}(CL_2) \tag{3}$$

$F_{RPB}(Wt)$ is waste pollutant load for specific Wt. Wt is waste type (TSS, CL_2 where TSS = Total Suspended Solid, CL2 = chloride. G= concentration, V_{wpl} is the volume of water pollutant load, and F_{total} is pollution burden reduction.

$$C_{cm} = Pr_{cm} \times m_{cm} \tag{4}$$
$$C_{T\_Ccost} = \sum C_{cm} \tag{5}$$

Where C_{cm} is the cost of chemical material cm for a year, Pr_{cm} is the chemical material price/kg, *and* m_{cm} is the weight of the chemical material (kg). C_{T_Ccost} is the total cost of chemical usage.

$$P_{tp} = U_p \times P_{ch} \tag{6}$$

Formula 6 shows the production operational costs calculation, where P_{tp} is the production operational costs calculation based on pump power consumption, U_p is the number of pumps, *and* P_{ch} = is the pump's power in kWh. Other pumps have specific power capacities, as shown in Table 1.

Table 1. Power capacity for pumps

No	Pump Name	power capacity in kWh (P_{ch})	Number of Pumps (U_p)
1	SWRO membranes cleaner pump (MCP)	27	1
2	Flocculant injection pump (FIP)	0.029	1
3	Coagulant injection pump (CIP)	1.57	1
4	Anti-scale injection pump (AIP)	0.022	1
5	Reducer injection pump (RIP)	0.37	1
6	High-pressure SWRO pump (SWRO)	285	2

$$C_{po} = d_{po} \times 24 \times P_{tp} \times Pr_{el} \tag{7}$$
$$C_{T\_pump} = \sum C_{po} \tag{8}$$

C_{po} is the operation cost of the PO pump, d_{po} is the total day of operation (recorded data), 24 is the total hours in a day, and Pr_{el} is the electricity price per kWh = IDR 1,444.7. C_{T_pump} is the total pump power consumption cost.

$$C_{bc} = C_{T\_Ccost} + C_{T\_eq} \tag{9}$$

C_{bc} is budgeted for chemical and pump maintenance costs.

Table 2. Pump Maintenance Cost

No	Equipment	Maintenance Cost (IDR)

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1	Saft/core pump	3,400,000
2	Packing and seal	250,000
3	Lubrication system	200,000
4	Bearing Pump	1,500,000
	Total (C_{T_eq})	5,350,000

Table 2 shows pump maintenance costs. We operate four pumps, which have different costs to service and maintain. Saft/core pumps have the highest cost, whereas lubrication system pumps have the lowest cost. Several factors contribute to high pump maintenance costs, including fluid type, frequency of use, and level of maintenance. Environmental factors like temperature, humidity, and corrosion can also affect maintenance costs.

Table 3. Anion Process Maintenance Cost (Chemical Cleaning Membrane)

No	Component Name	Price (IDR)	Usage (Kg)	Total Price (IDR)
1	PC 98	74,000	418	30,932,000
2	PC 40	46,700	57	2,661,900
3	PC 77	53,200	484	25,748,800
4	PC 11	38,500	23	885,500
			Total (C_{T_mem})	60,228,200

Table 3 shows the cost of maintenance of the anion process, which is the cost of chemical cleaning the membrane. Anion process maintenance costs vary with factors such as frequency of chemical cleaning, chemicals used, membrane size and complexity, and expertise required. Overall, these factors contribute to ensuring optimal performance of the anion process.

$$C_{T\_mcost} = C_{T\_eq} + C_{T\_mem} \tag{10}$$

C_{T_mcost} is the total maintenance cost, C_{T_eq} is the total pump maintenance cost, and C_{T_mem} is the total anion process maintenance cost.

Cost Savings Calculation. $\bar{L}_{\sigma}$ is the average production flow in 2022, which is 43 m3/hour, and t_{top} is the total anion operation time, which is 2,594 hours.

$$V_{eff\_w} = \bar{L}_{\sigma} \times t_{op} \tag{11}$$
$$C_{\partial d} = Pr_{wa} \times \ t_{o\_an} \times V_{eff\_w} \tag{12}$$

$C_{\partial d}$ is the cost efficiency of demineralization water use, *and* Pr_{wa} wa is the price water of anion product = IDR 3,800 / m3. t_{o_an} is the anion operating time, which is 2,734.

$$C_{T\_Ecost} = C_{T\_Ccost} + C_{T\_pump} + C_{T\_mcost} + C_{\partial d} \tag{13}$$

C_{T_Ecost} is the total cost savings. It is obtained from the additional cost of chemical material C_{T_Ccost}, the total pump power consumption C_{T_pump}, *the* total maintenance cost C_{T_mcost} and the cost efficiency of demineralization water usage $C_{\partial d}$.

RESULT AND DISCUSSION

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Implementing a 3 in 1 anion operation pattern program impacts the component replacement routine and improves the process. We have reduced the frequency of anion bed replacements from once a month to once every three months. Furthermore, these activities make water use more efficient, reducing chemical usage and environmental pollution.

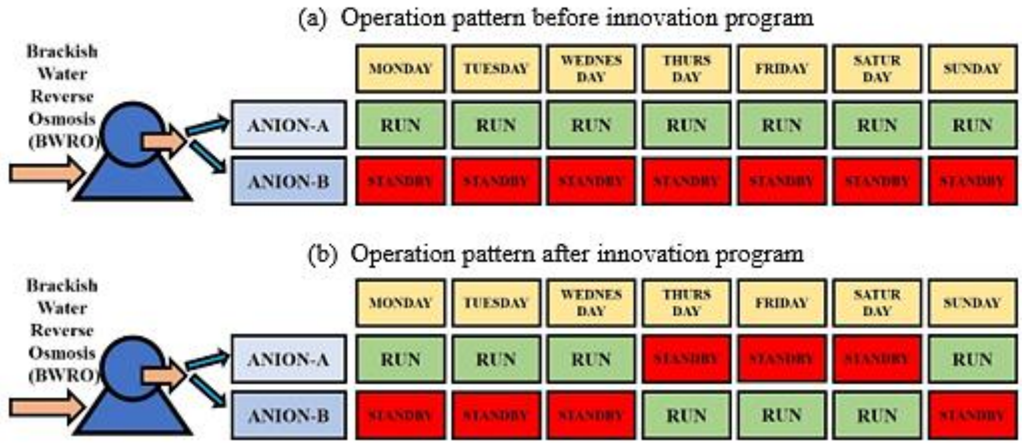

Figure 3. Operation Pattern Before and After the Innovation Program

To address the frequent need to replace anion beds can be addressed, this program was designed. Undoubtedly, the regeneration of components and chemicals directly affects the use of demineralized water and waste generation. This revolutionary process involves a three-day run of the anion bed filter (as shown in Figure 3), followed by a one-day standby and two-day maintenance period, during which the filter is operated. During the three-day run of the anion bed filter, the contaminated water passes through the filter, and the anion resin in the bed attracts and removes negatively charged ions. The result of this process is the purification of the water, which is an essential factor for power plants. As soon as the three-day run is over, the filter enters a one-day standby and two-day light maintenance period. After settling for three days, any remaining impurities are reactivated for the next three-day cycle, during which they can be filtered again. As we mentioned earlier, it is essential to keep in mind that during the one-day standby period, it is possible that some impurities may not fully settle, which means that they may be carried over to the next cycle if they are not fully settled during the three days. Therefore, two days of treatment are required. In order to maintain the optimal performance of the anion bed filter, additional maintenance or cleaning may need to be completed as a result of this condition.

Figure 4. Anion Bed Water Treatment Plant

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In Figure 4, we can see the form of an anion bed water treatment plant. Negative ions (anions) are exchanged with positive ions (cations) in ion exchange. Water is initially stored in a water storage tank before the plant treats it. This tank ensures that a constant water source is available throughout treatment. An anion bed system is pre-treated to prevent suspended solids and organic matter from entering. Filtration, sand filtration, and activated carbon adsorption are part of the pretreatment process. The major components and processes involved in removing negatively charged ions from water.

Pre-Implementation Condition. We measured the water treatment plant for one month before the anion bed replacement to evaluate the filtration system. The following are the costs and materials required for regeneration operations:

- Wastewater discharge in 2021 = 35263.70 m3.
- Chemical requirements = 4800 kg.
- Total water usage = 258,597.4 m3.
- Water pollution load =
  - $TSS = 0.001261\, TSS$
  - $CL_2 = \ 0.0000245\, Tons\ CL_2$

Post-Implementation Condition. In the post-implementation period, bed anions' replacement frequency was reduced. The replacement process is done every three months. These measurements indicate that the program is successfully executed, as shown below:

- Wastewater discharge in 2021 = 33851,30 m3.
- Chemical requirements = 1920 kg.
- Total water usage = 232.190 m3.
- Water pollution load =
  - $TSS = 0{,}000624\, TSS$
  - $CL_2 = \ 0.00000714\, Tons\ CL_2$

Our analysis shows that several materials used to measure program success have decreased. The innovation program has reduced the anion bed filter's workload (flow rate). Temperature significantly affects ion bed saturation (Kosim et al., 2021). This condition can affect the reduction in the anion's regeneration intensity.

Environmental Impact of Innovation Program. Therefore, the resulting environmental impact was reduced wastewater pollution load in 2022. The reduction for TSS = 0.000624 tonnes and Cl2 = 0.00000714 tonnes. It is equivalent to cost savings of IDR 1,164,543,907,450.67

The Calculation of the Innovation Program. Absolute value and waste pollutant load calculation:

$$|At_{abs}| = 43 \times 2{,}594 = 111{,}542 m^3$$

$$F_{RPB}(TTS) = \frac{5.6mg}{L} \times 111{,}542m^3 = \ 0.000624\, Ton$$

$$F_{RPB}(CL_2) = 0.064mg/L \times 111{,}542m^3 = \ 0.00000714\, Ton$$

$$F_{total} = 0.000624\, Ton + \ 0.00000714\, Ton = \ 0{,}00063114\, Ton$$

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According to the calculations based on (formulas 1, 2, and 3), the absolute value calculation is $111{,}542m^3$, the waste pollutant load is 0.000624 Ton for TTS, and 0.00000714 Ton for CL_2 , so we got the pollution burden reduction is 0,00063114 Ton.

Savings Calculations. Savings calculations are based on the cost of chemicals used in the anion bed unit's water treatment process. Table 3 shows the details of chemical prices (Source: Chemical Prices from Supplier Offers, namely PT. TOYA in 2022). Table 4 shows the total chemical usage in 2022.

Table 4. The Price of Chemical Material

No	Chemical	Price
1	Coagulant N3276	IDR 23,300 / kg
2	Flocculant N9901	IDR 117,800 / kg
3	Reducer N7408	IDR 23,100 / kg
4	Anti-Scale PC1020T	IDR 67,760 / kg

Table 5. The Total Chemical Usage Per Year (source: Logbook Data on Chemical Usage for 2022)

No	Chemical	Weight Usage
1	Coagulant N3276	5,675 kg
2	Flocculant N9901	180 kg
3	Reducer N7408	5,080 kg
4	Anti-Scale PC1020T	4,300 kg

Based on the use of chemicals, we calculate the production operational costs (formula 4 and 5) as follows:

$$C_{\text{Coagulant}} = 23{,}300 \times 5{,}675 = IDR\ 132{,}227{,}500$$

$$C_{\text{Flocculant}} = 117{,}800 \times 180 = IDR\ 21{,}204{,}000$$

$$C_{\text{Reducer}} = 23{,}100 \times 5{,}080 = IDR\ 117{,}348{,}000$$

$$C_{\text{Anti-Scale}} = 67{,}760 \times 4{,}300 = IDR\ 291{,}368{,}000$$

$$C_{\text{NaOH}} = 6{,}500 \times 320 = IDR\ 2{,}080{,}000$$

$$C_{\text{HCl}} = 4{,}350 \times 520 = IDR\ 2{,}262{,}000$$

$$C_{T\_Ccost} = C_{\text{Coagulant}} + C_{\text{Flocculant}} + C_{\text{Reducer}} + C_{\text{Anti-Scale}} + C_{\text{NaOH}} + C_{\text{HCl}}$$
$$C_{T\_Ccost} = 132{,}227{,}500 + 21{,}204{,}000 + 117{,}348{,}000 + 291{,}368{,}000 + 2{,}080{,}000 + 2{,}262{,}000 = IDR\ 566{,}489{,}500$$

The C_{T_Ccost} represents the total cost of chemical usage. Following formula 5, the total cost of chemical usage is IDR 566,489,500. The result is derived from the sum of the costs associated with the cost of the Coagulant, Flocculant, Reducer, Anti-Scale, NaOH, and HCl.

Calculation of production operational costs based on pump power consumption (formula 6) as follows:

$$P_{tp(pump\_SWRO)} = 2 \times 285 = 570\ kWh$$

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This calculation obtains the total kWh from the high-pressure SWRO pump (SWRO), which is 570 kWh.

The calculations in Table 6 use formulas 7 and 8, which calculate the pump operation cost C_{po}, and the total pump power consumption cost C_{T_pump}

Table 6. Pump operation costs

No	Pump Name	power capacity kWh (P_{ch})	Number of Pumps (U_p)	Total power capacity	Day operation (d_{po})	Hour	electricity price kWh (Pr_{el})	Pump operation cost (C_{po})
1	SWRO membranes cleaner pump (MCP)	37	1	37	2	24	1,444.7	2,565,787.2
2	Flocculant injection pump (FIP)	0.029	1	0.029	256	24	1,444.7	257,410.87
3	Coagulant injection pump (CIP)	1.57	1	1.57	256	24	1,444.7	13,935,691.78
4	Anti-scale injection pump (AIP)	0.022	1	0.022	256	24	1,444.7	195,277.21
5	Reducer injection pump (RIP)	0.37	1	0.37	256	24	1,444.7	3,284,207.61
6	High-pressure SWRO pump (SWRO)	285	2	570	256	24	1,444.7	5,059,454,976
Total pump power consumption cost(C_{T_pump})								**5,079,693,350.67**

Table 6 shows that the total power consumption cost for all pumps is IDR 5,079,693,350.67. The system has six pumps: the SWRO membrane cleaner pump (MCP), the Flocculant injection pump (FIP), the Coagulant injection pump (CIP), the Anti-scale injection pump (AIP), the Reducer injection pump (RIP), and the High-pressure SWRO pump (SWRO).

The following calculation is the chemical and pump maintenance cost C_{bc} from formula 9. We add up the total cost of chemical usage C_{T_Ccost} and the total pump maintenance cost from Table 2 (C_{T_eq}).

$$C_{bc} = IDR\ 566{,}489{,}500 + IDR\ 5{,}350{,}000 = IDR\ 571{,}839{,}500$$

Based on formula 10, the total maintenance cost C_{T_mcost}, we add up the total pump maintenance cost from table 2 C_{T_eq}, and anion process maintenance cost C_{T_mem}, *and* the result is as follows:

$$C_{T\_mcost} = IDR\ 5{,}350{,}000 + IDR\ 60{,}228{,}200 = IDR\ 65{,}578{,}200$$

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Based on formulas 11 and 12, Eff water volume calculation V_{eff_w} is the average of production flow in 2022 $\bar{L}_{\sigma}$ times the total of anion operation time t_{op}. The cost efficiency of demineralization water usage $C_{\partial d}$ is the price water of anion product Pr_{wa} times the anion operating time (t_{o_an} times Eff water volume calculation V_{eff_w}.

$$V_{eff\_w} = 43 \times 2{,}594 = 111{,}542\ m^2$$

$$C_{\partial d} = IDR\ 3{,}800 \times\ 2{,}734 \times 111{,}542\ m^2 = IDR\ 1{,}158{,}832{,}146{,}400$$

The final calculation (total cost savings C_{T_Ecost} is that we add up the total cost of chemical usage C_{T_Ccost}, total pump power consumption cost C_{T_pump} total of maintenance cost C_{T_mcost} and cost efficiency of demineralization water usage $C_{\partial d}$.

Table 7. The Final Calculation

No	Parameter	Cost
1	Total cost of chemical usage (C_{T_Ccost})	IDR 566,489,500
2	Total pump power consumption cost (C_{T_pump})	IDR 5,079,693,350.67
3	Total of maintenance cost (C_{T_mcost})	IDR 65,578,200
4	Cost efficiency of demineralization water usage ($C_{\partial d}$)	IDR 1,158,832,146,400
	The total cost savings (C_{T_Ecost})	**IDR 1,164,543,907,450.67**

Innovation Programs Add Value. As a result of this innovation program, added value has been created in the value chain. Profits from the "The Implementation of 3 in 1 Anion Operation Pattern" program have been realized as follows:

1. Profits are realized by producers/companies as follows:
   a. There is the possibility of cost savings of IDR 1,164,543,907,450.67 for the company in 2023.
   b. With this program, we can save 111,542 m2 of water.
   c. A reduction in the workforce is required to handle waste pollution.
   d. The start-up process has been accelerated due to excess raw water supplies (demineralization) for electricity production in the area.
2. Benefits to consumers, Perusahaan Listrik Negara, include:
   a. Enhance the monitoring of electricity conditions throughout the nation by making the PT PLN Nusantara Power Unit Tanjung Awar-Awar generating unit available. Therefore, The unit can maintain a power reserve of up to 30% because it does not experience problems related to a lack of Demin water as a raw material for driving the turbine.
   b. Prevent derating (lack of electricity due to problems within the generating unit) and lack of raw water (demineralization) in the boiler treatment process.
3. Suppliers: PT PLN Nusantara Power Unit Tanjung Awar-Awar allocated IDR 571,839,500 in 2023 to implement an innovation program to supply chemical needs for the anion bed replacement process.

Innovation Program Toward the Scope of Life Cycle Assessment (LCA) Study. The implementation of 3 in 1 anion operation pattern program is being implemented at the WTP, which has entered the scope of the 2022 life cycle assessment (LCA) study. WTP units are included in the production scope of the life cycle assessment of electrical products. The implementation of this program has an impact on the Wasted Life Cycle (Lifecycle services to repair), where there is a

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reduction in the water pollutant burden due to process improvement due to the implementation of 3 in 1 anion operation pattern program.

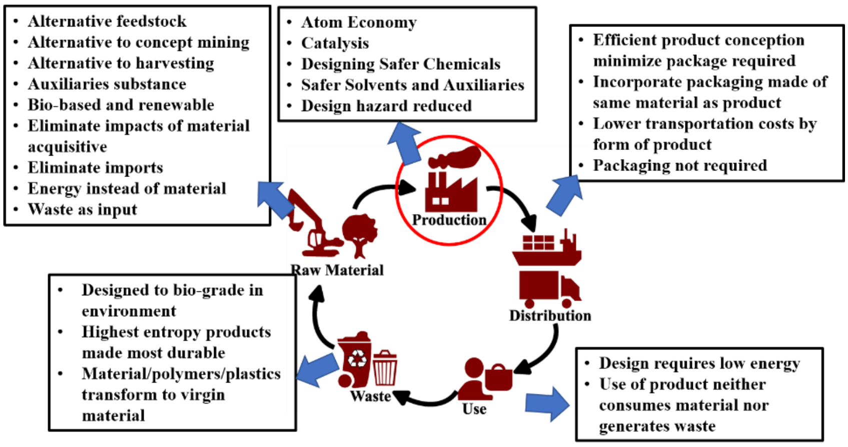

Figure 5. Potential areas for improvement as a result of implementation

A few potential areas for improvement in the product's performance are identified to mitigate adverse environmental effects. By implementing 3 an 1 anion operation pattern program, we improve the equipment for producing a power plant. Figure 5 shows how the new design involves atomic economics, catalysis, safer chemicals, and hazard reduction in sub-focus areas. Recycling components and chemicals affect demineralized water usage and waste generation. By reducing saturation, equipment lasts longer, and fewer chemicals are needed. This effort has significantly decreased energy consumption, chemical usage, and other associated pollutants. As a result, the environment is greener and more sustainable, and the company is more profitable. Aside from that, the new system is easier to maintain and troubleshoot, making production more efficient and cheaper. We use a cradle-to-grave model to accomplish this as a scientific method of Life Cycle Analysis (LCA). LCA includes five stages: raw material, processing, transportation, usage, and waste disposal. These five phases helped us calculate the product's total carbon footprint. It has significantly reduced the environmental impact, especially when implementing 3 in 1 anion pattern to water treatment plants on the processing machine in the production phase.

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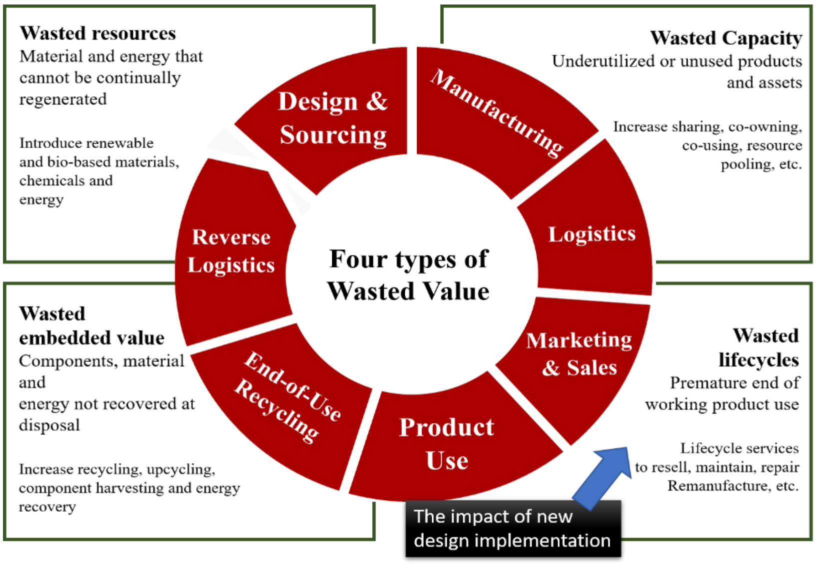

Figure 6. Four categories of waste (Lacy et al., 2020)

According to the circular business model of Lacy et al. (2020), waste falls into four categories: wasted resources, wasted capacity, wasted embedded value, and wasted life cycles (as shown in Figure 6). Wasted resources are materials and energy that cannot be recovered for practical use in the future, such as fossil fuels (Erawan et al., 2024). Wasted capacity is unutilized products and assets. Wasted life cycles are when a product is thrown away prematurely because it is not designed to be reused. Waste-embedded value is anything that is not recovered from disposed things and put back into use. Using this circular concept, we reduced the amount of energy and heat lost during processing by installing an innovative program. As a result of the circular model outlined above, our innovation project falls under the wasted life cycle category because we implemented a 3 1 anion operation pattern program, which decreased the workload and flow rate on the filter bed, thus optimizing the negative anion exchange process. Consequently, anion bed component replacement frequency is reduced.

CONCLUSION

Perseroan Terbatas (PT) Perusahaan Listrik Negara (PLN) Nusantara Power Unit Tanjung Awar-Awar Power Plant is a coal-fired power plant company in Tuban Regency, East Java, Indonesia. With 2 x 350 MW generators, we produce electricity to support Java and Bali islands. The company is dedicated to the environment, with its primary goal being reducing its carbon footprint. Additionally, we utilize a highly efficient combustion process that makes it efficient and cleaner. In this improvement, PT PLN Nusantara Power Unit Tanjung Awar-Awar aims to minimize water pollution from waste and optimize water efficiency. In 2022-2023, PLN introduced an enhanced program called "THE IMPLEMENTATION OF 3 IN 1 ANION OPERATION PATTERN". This approach helps to reduce the workload and flow rate on the filter bed, thus optimizing the negative anion exchange process. Consequently, the frequency of anion bed component replacement is reduced. This operating method is feasible because the WTP is equipped with two units of anion beds: Bed-A and Bed-B. During the first three days of operation, Anion Bed-A is utilized, while Anion Bed-B remains on standby. As a result of this revised operating pattern, the saturation level in the anion bed has decreased. The contribution of this program is: 1) Component replacement: The anion bed replacement has been reduced from once a month before the program to once every three

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months after the program has been completed. 2) significant reductions in wastewater pollution load in 2022 of TSS=0,000624 tonnes and $CL_2 = 0.00000714$ tonnes. That is equivalent to IDR 1,164,543,907,450.67 in cost savings. In further developments, we are committed to utilizing environmentally friendly chemicals. The use of environmentally friendly chemicals is good for the environment and humans. In addition, it promotes sustainable practices and makes the environment cleaner. However, switching to eco-friendly chemicals is challenging since they are more expensive and difficult to find. However, our company will invest in research and development to find suitable alternatives in the future.

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